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NASA CR 102501

FINAL REPORT ON ANALYSIS OF

SECOND BREAKDOWN

Foundation
FOR THE ADVANCEMENT OF GRADUATE STUDY IN ENGINEERING

FINAL REPORT ON ANALYSIS OF

SECOND BREAKDOWN

Contract number- NAS-8-21286

Marshall Space Flight Center

Newark College Of Engineering

Newark, New Jersey

In this our final report on contract number NAS-8-21286 on second breakdown two conclusions are quite clear as a result of all the experimental data that we generated here at NCE.

One is that most power transistors get into sedond breakdown at a lower current when the temperatures are very low. It is also clear that some transistors do not follow this behávior. But they are few and far between. In an informal communication with the very active group at Fort Monmouth in Second Breakdown studies led by Barney Reich and Ed. B. Hakim, confirmation of this fact occured. They were originally surprised at our finding but later they pursued the subject further and confirmed our findings. We are of course unable to explain the exceptions nor are we yet very clear on explaining the greater venerability to second breakdown at lower temperatures. This because there is no doubt in our minds about the well stablished hot spot theory. We propose to persue this matter further since.

These findings of course are very significant in that what might be considered safe and therefore super at low temperatures because the cause of failure is heat (or hot spot) actually fails when we would have normally felt overconfident.

The second finding is that where as there is very mild Co-relation between electrical noise and early second breakdown this is extremely extremely mild being +0.465. Much more work needs to be done in this field before more light can be thrown on this subject.

Data was taken on this topic spread over a long period of time and data collected at NCE is reported is this report in detail.

Mr. Durwin, a graduate student here and at University of New Hampshire has theorized this data further and any interested reader of this report can further discuss this subject.

R. P. Misra, PhD.
Professor of Electrical Engineering
and Reliability in Electronics.

THIS REPORT TO BE SEEN ONLY BY THOSE PERSONS

DIRECTLY INVOLVED IN THIS PROJECT

Subject:	Cost and Performance Report
Contract No.:	NAS8-21286
Item Nomenclature:	Chemical and Structural Analysis of Second Breakdown
Control No.:	DCN 1-8-60-00155(IF)
Period of Report:	April 1,1969-April 30,1969 And final reporting August 1969

a. Man Hours

Total in April	258
Cumulative	3195.5

b. Funds

Salaries	1066.13
Equipment and Supplies	--
Overhead	--
Total Expenses For The Period	1066.13
Outstanding Commitment	--
Cumulative Total	22,631.00
% Total Spent	100%

c. Work Completion (to date)

During This Period	6%
Cumulative	100%

<u>Second Breakdown Vs Temperature</u>:-

The status of second breakdown currents,(and the 1st breakpoint only has been sonsidered in the event of multiple breakpoints) shows the general pattern as indicated in the early pages of this report.

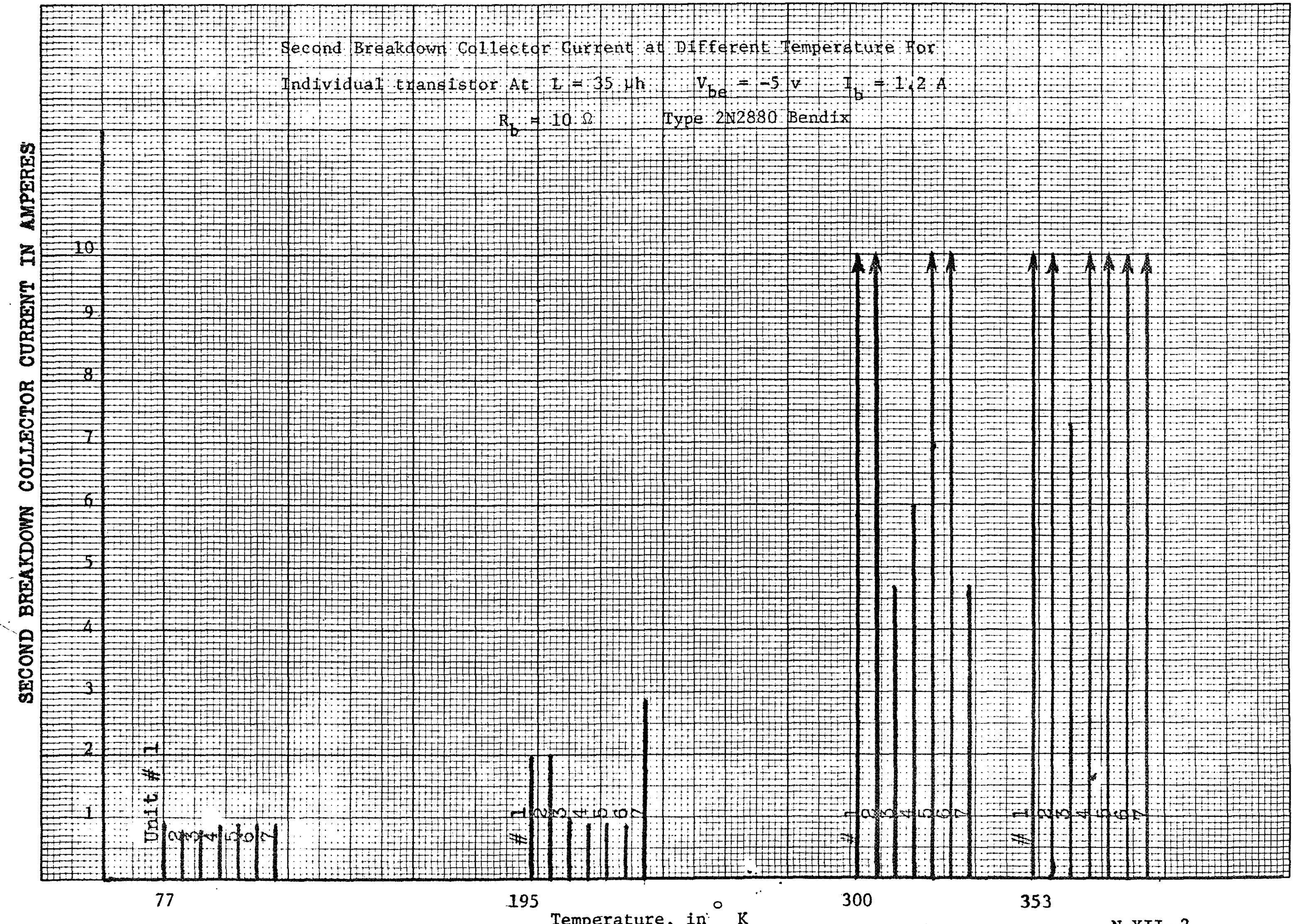
It was hoped that we could make further measurements at cryogenic temperature of liquid Heluim but our difficulties in setting up this equipment still persists and so this point could not be taken. Measurements made at this point when they become available will certainly give us more insight into the reasons of the transistor behavior.

The inconsistency in the behavior of some transistors is probably caused due to response time since there is no doubt that ultimately the Second breakdown failure is caused due to the hot spot.

The attached curves are self explanatory.

Fig 2 A

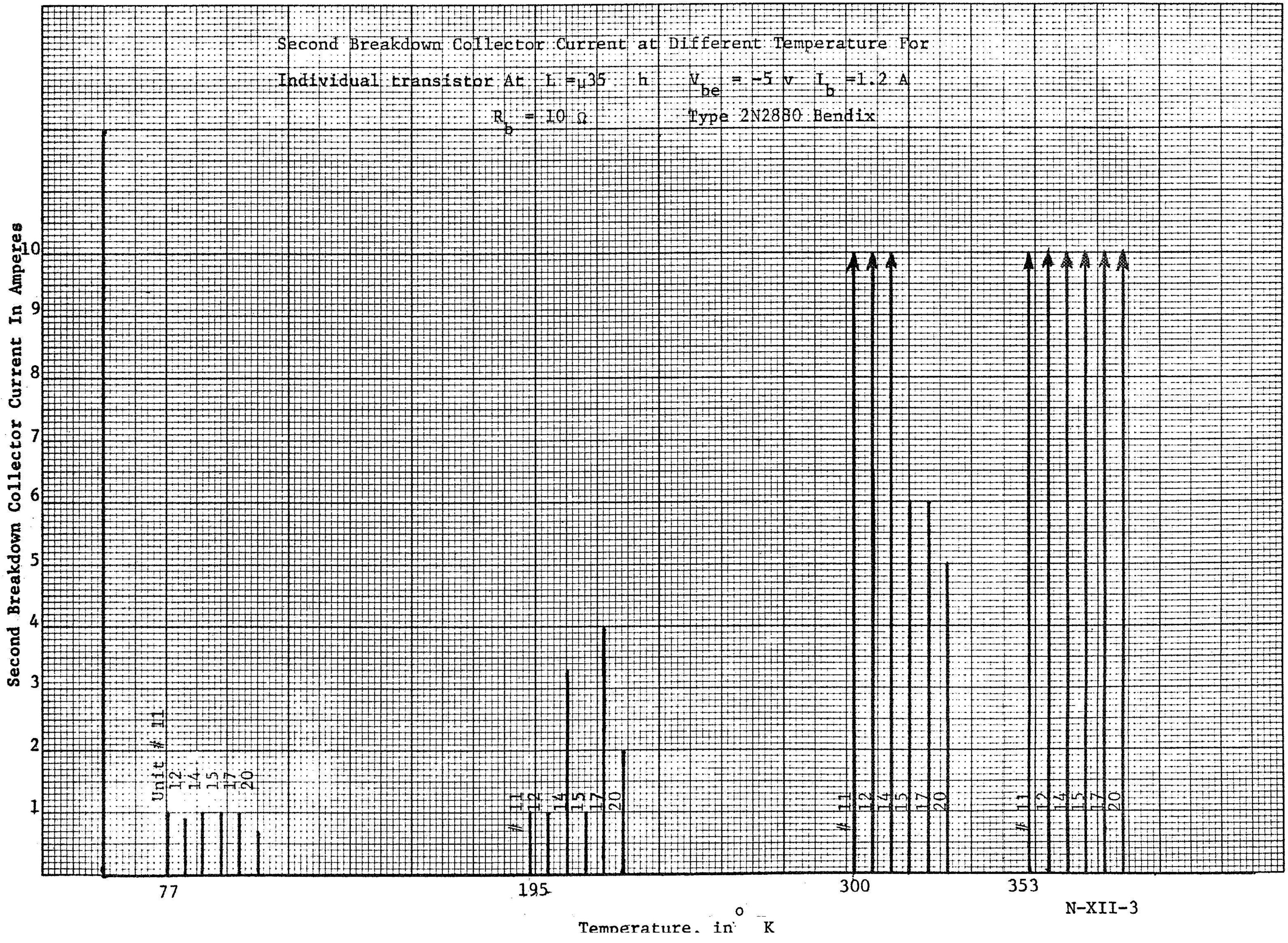
Ref. N-X1-8



N-XII- 2

Fig 2 B

Ref. N-X1-9



N-XII-3

Fig 3

Ref. N-X1-10

Second Breakdown Collector Current at Different Temperature For Individual Transistor At $L = 35\ \mu h$ $V_{be} = -5\ v$ $I_b = 1.2\ A$

$R_b = 10\ \Omega$ Type 2N2880 Bendix

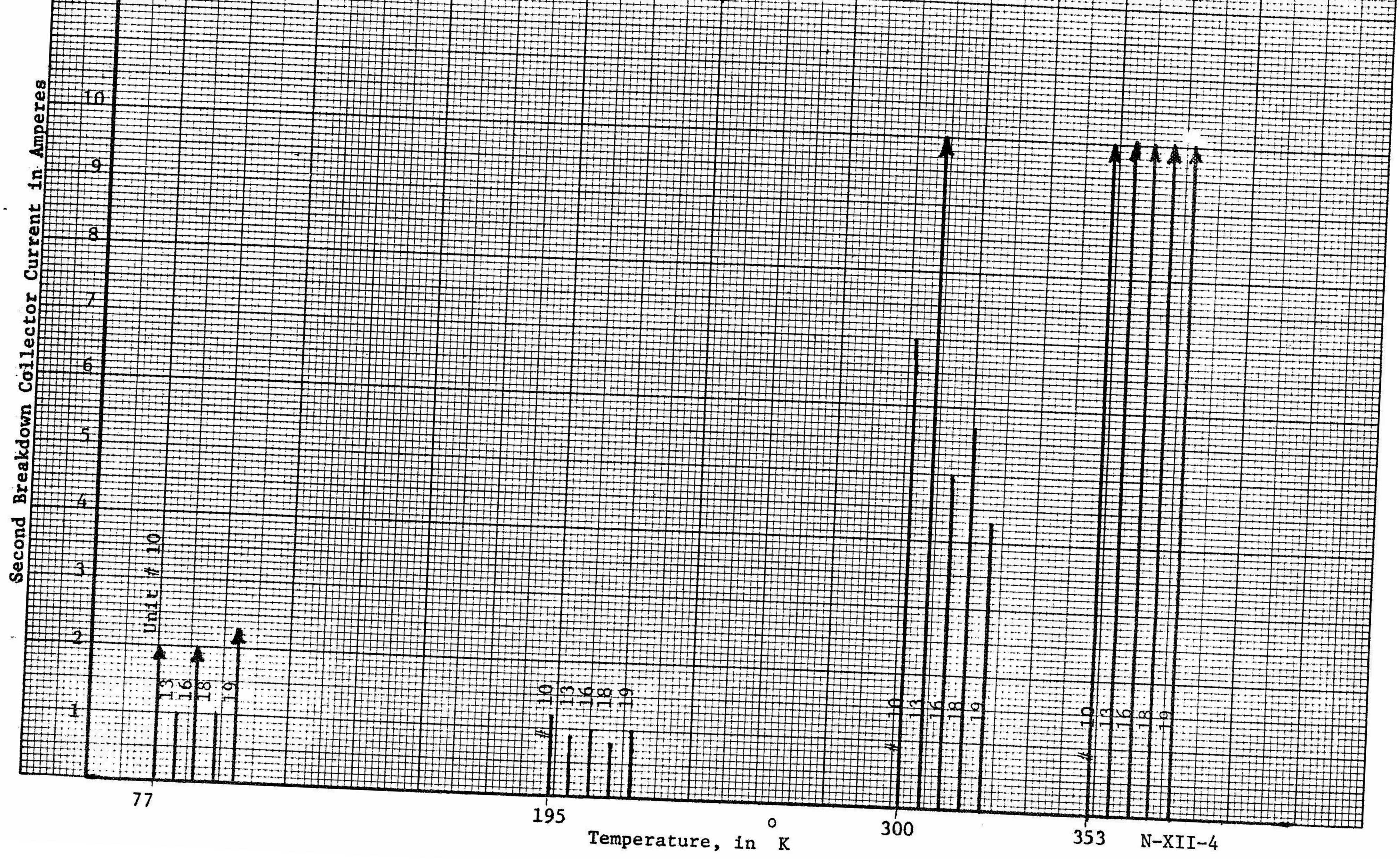
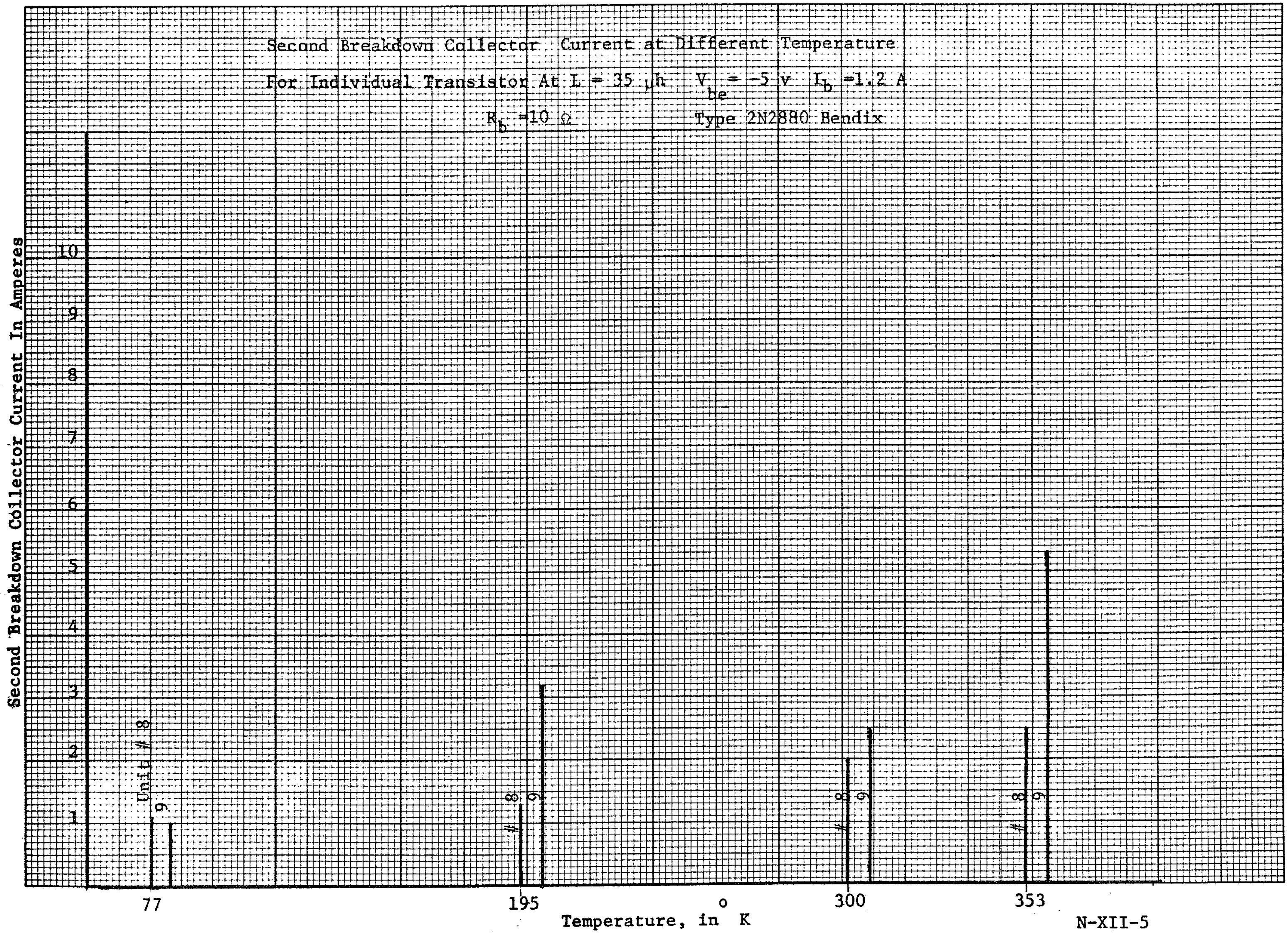


Fig. 4 Ref. N-X1-11



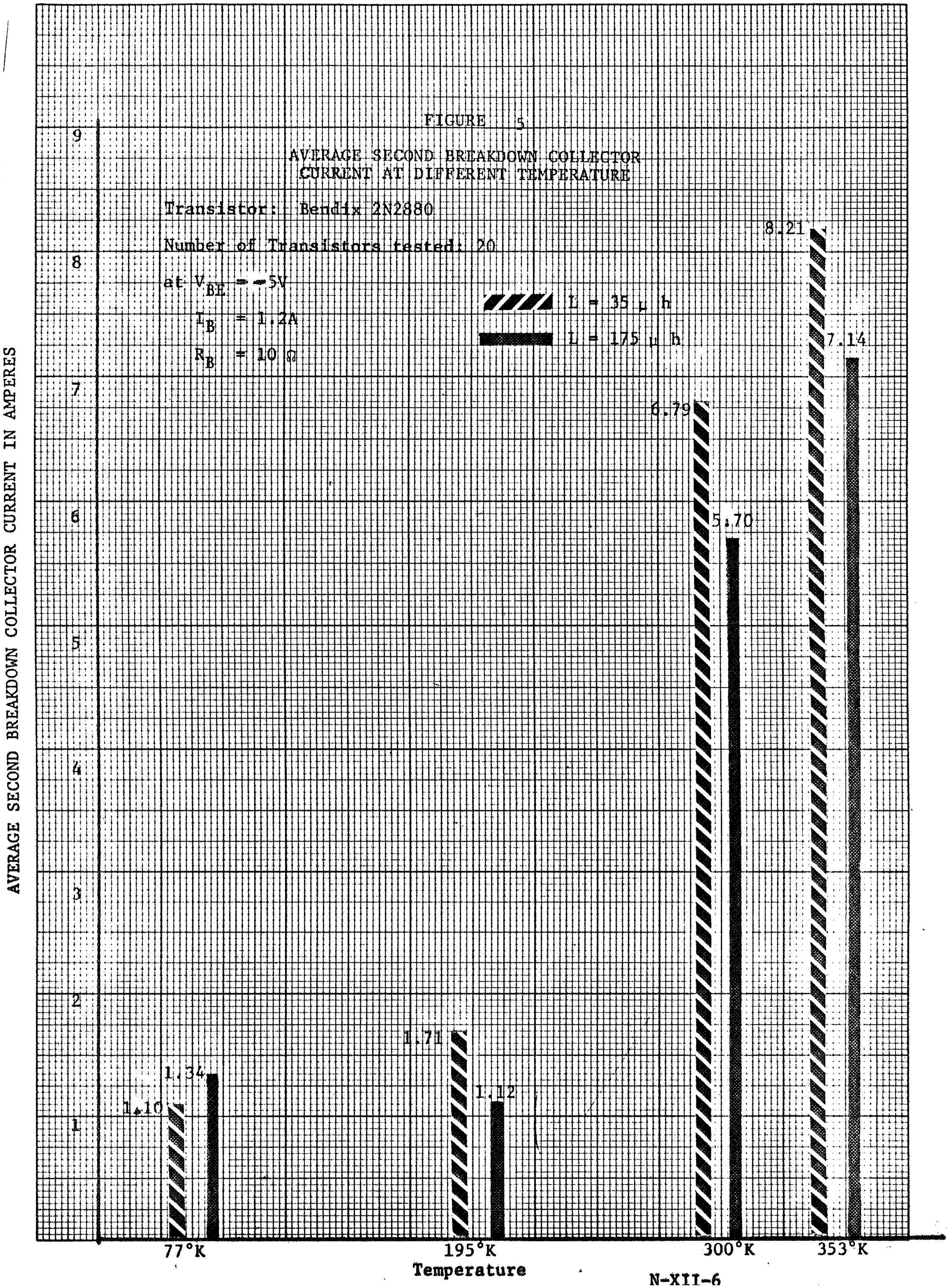
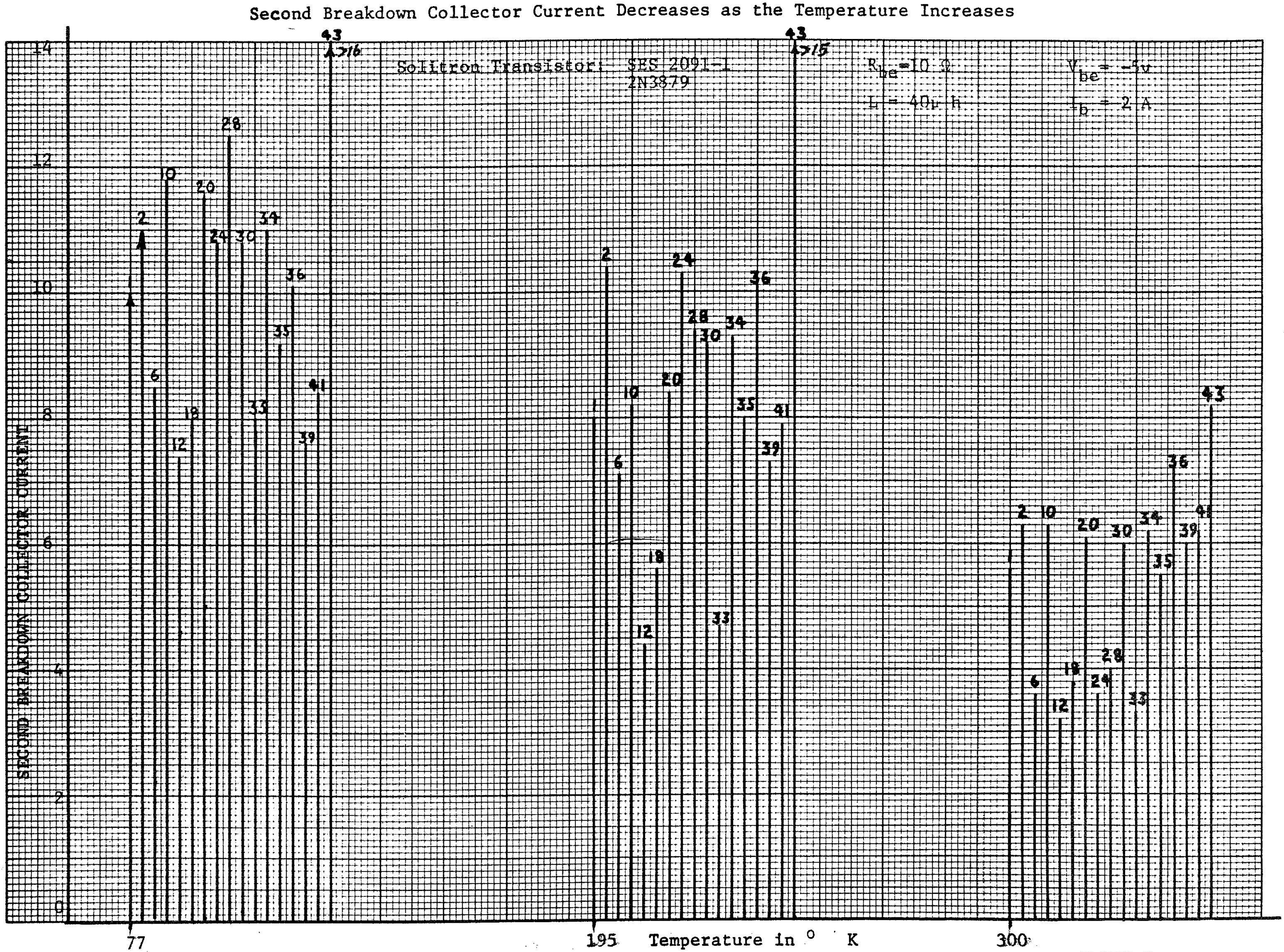


FIGURE 5
AVERAGE SECOND BREAKDOWN COLLECTOR CURRENT AT DIFFERENT TEMPERATURE
Transistor: Bendix 2N2880
Number of Transistors tested: 20
at V_{BE} = -5V
I_B = 1.2A
R_B = 10 Ω
L = 35 μ h
L = 175 μ h
AVERAGE SECOND BREAKDOWN COLLECTOR CURRENT IN AMPERES
1
2
3
4
5
6
7
8
9
1.10
1.34
1.71
1.12
6.79
5.70
8.21
7.14
77°K
195°K
300°K
353°K
Temperature

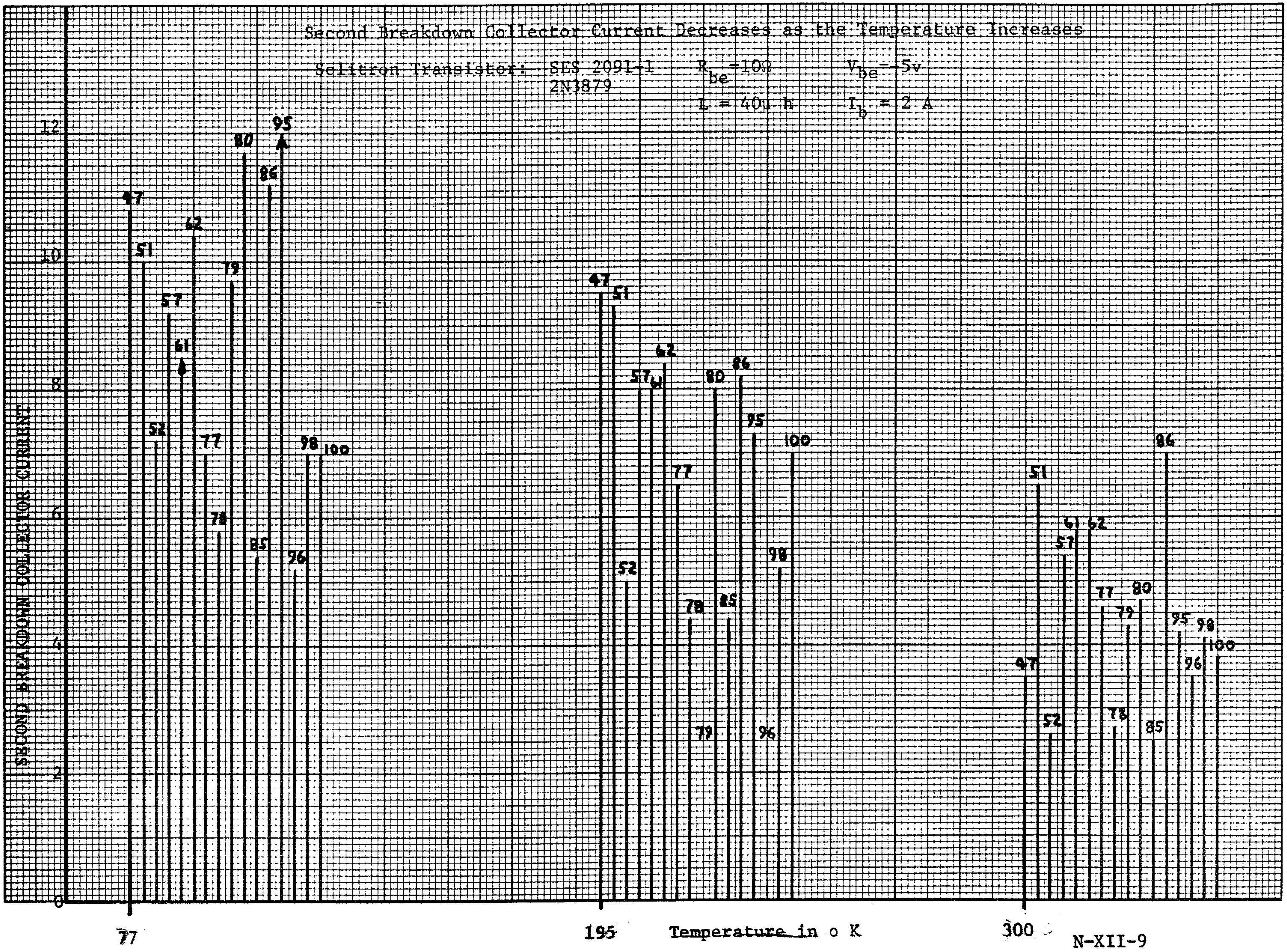
DATA ON

SES 2091-1

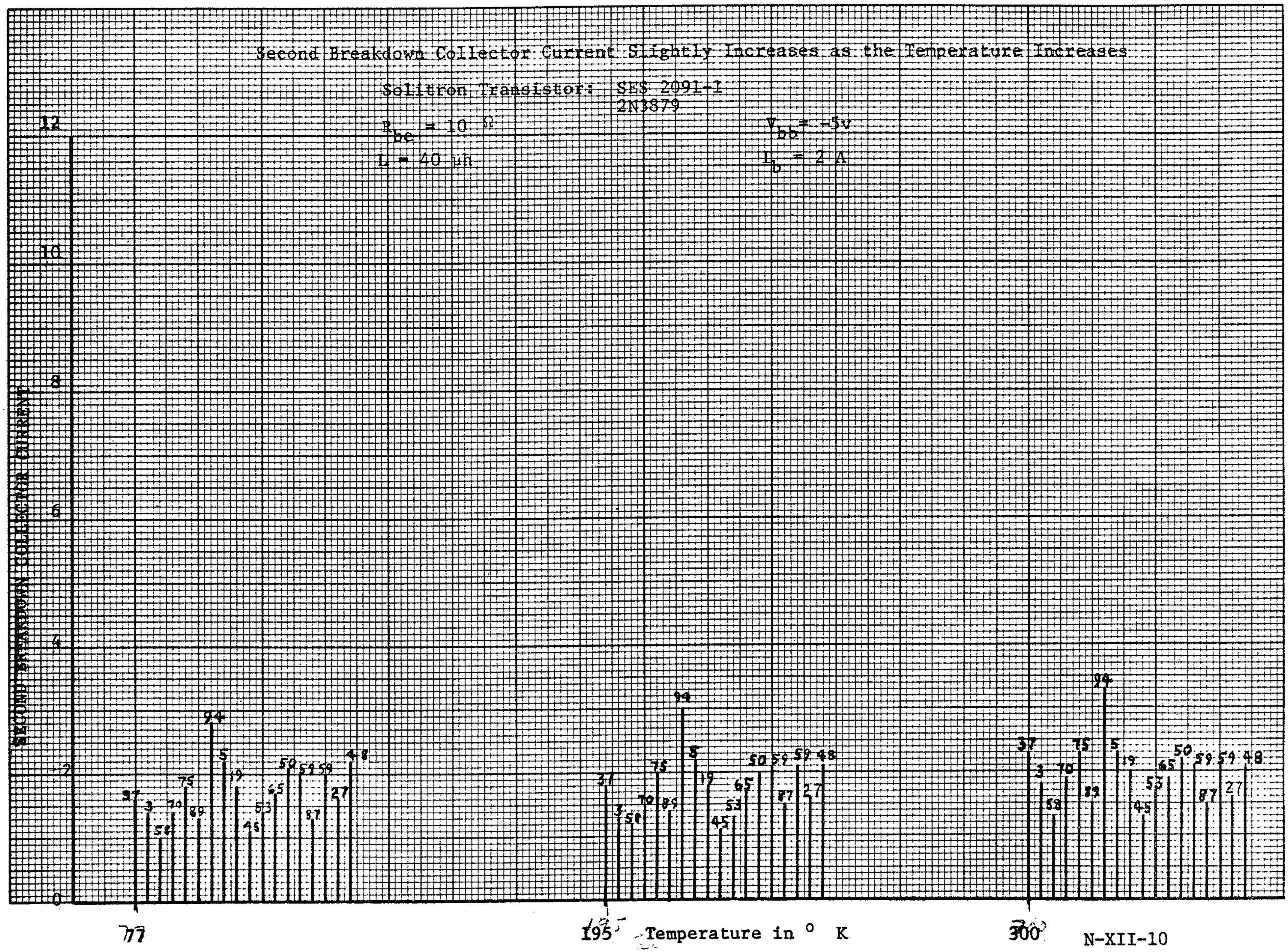
2N3879


Second Breakdown Collector Current Decreases as the Temperature Increases
Solitron Transistor: SES 2091-1
2N3879
R_{be} = 10 Ω
L = 40μ h
V_{be} = -5v
I_b = 2 A
SECOND BREAKDOWN COLLECTOR CURRENT
Temperature in ° K
77
195
300
43 >16
43 >15

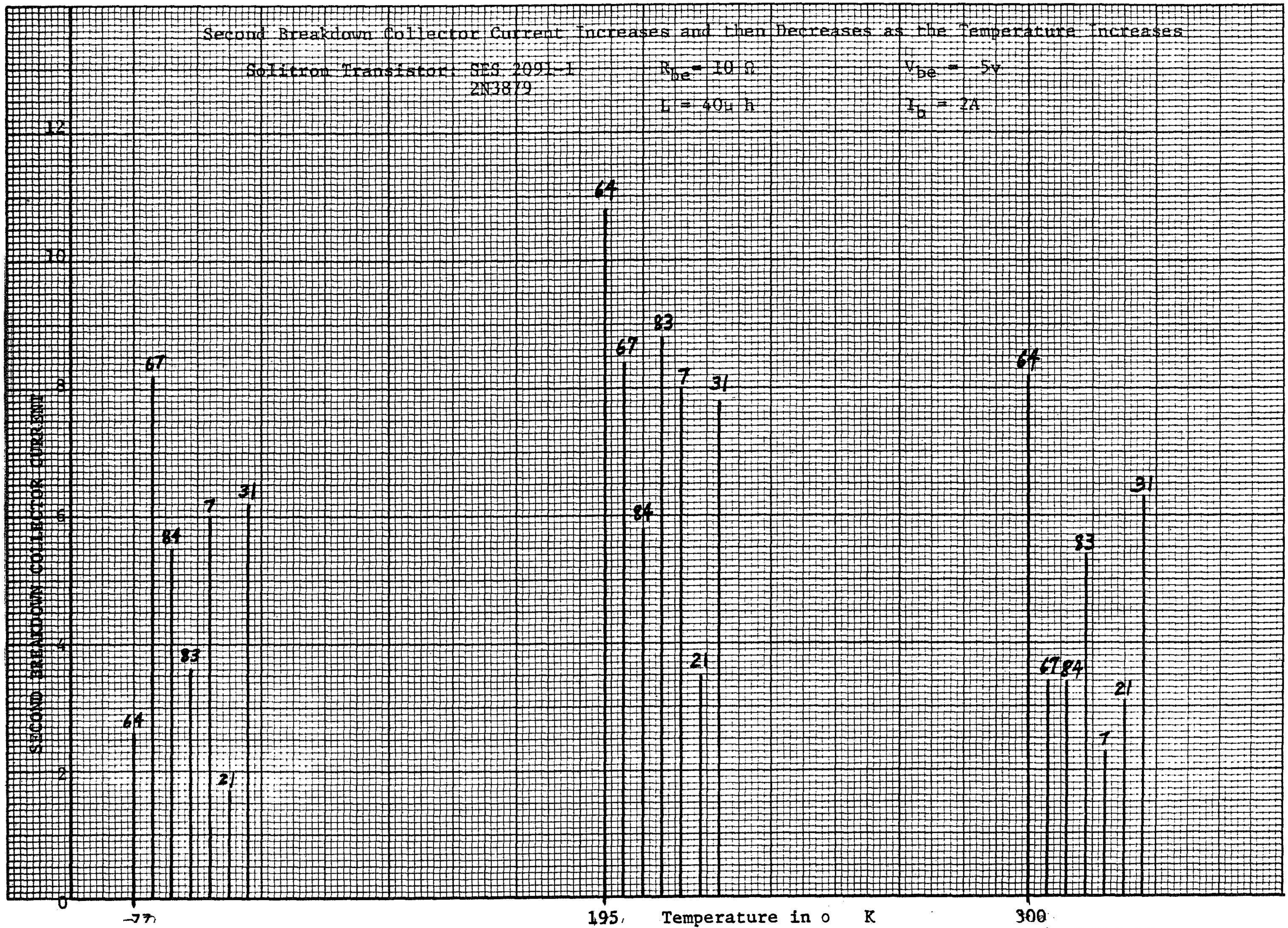
N-XII-8


Second Breakdown Collector Current Decreases as the Temperature Increases
Solitron Transistor: SES 2091-1 2N3879
R_{be} =10Ω
V_{be} = -5v
L = 40μ h
I_b = 2 A
SECOND BREAKDOWN COLLECTOR CURRENT
0
2
4
6
8
10
12
77
195
300
Temperature in o K
47
51
52
57
61
62
77
78
79
80
85
86
95
96
98
100

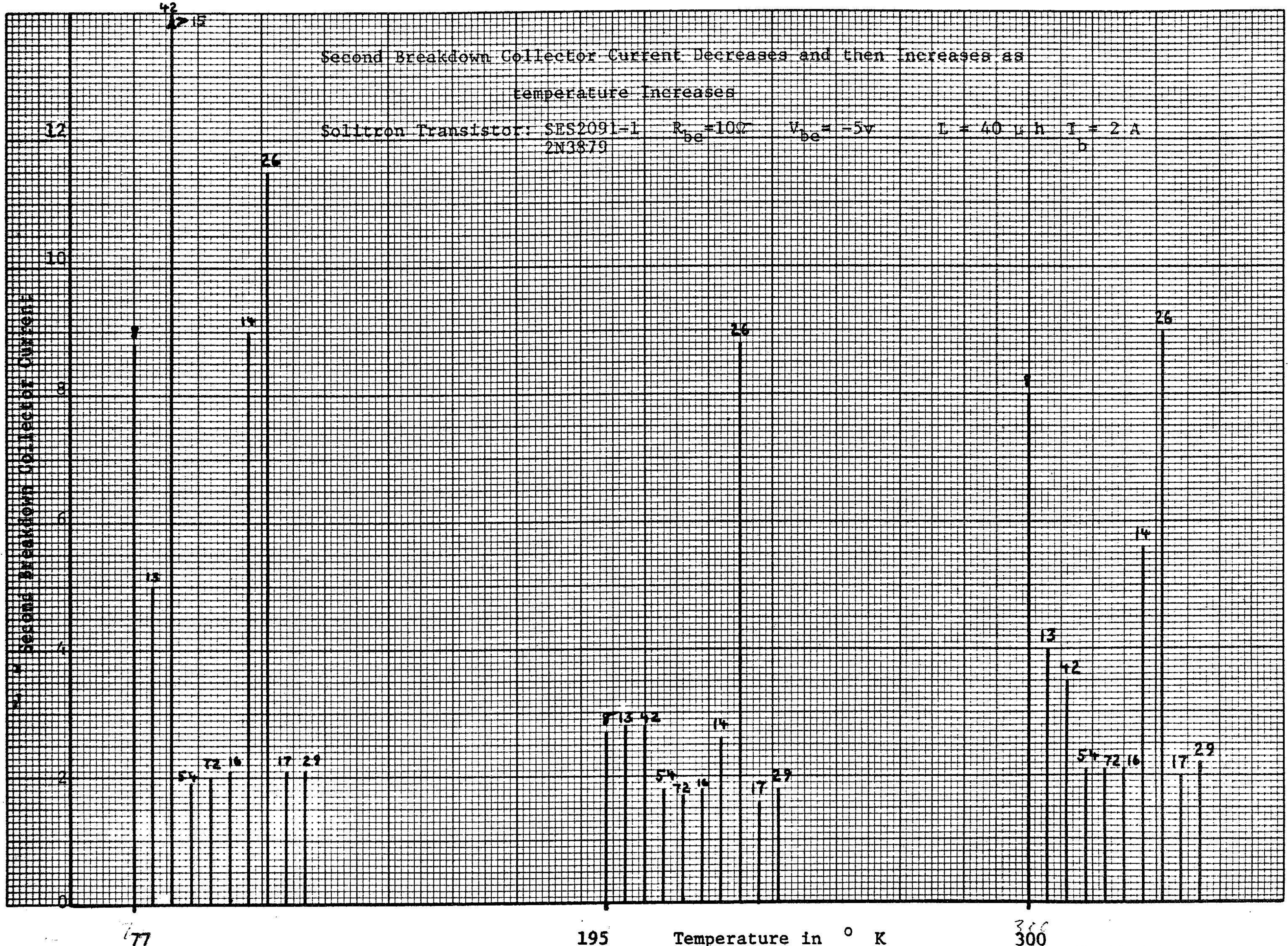
N-XII-9


Second Breakdown Collector Current Slightly Increases as the Temperature Increases
Solitron Transistor: SES 2091-1
2N3879
R_{be} = 10 Ω
L = 40 μh
V_{bb} = -5v
I_b = 2 A
SECOND BREAKDOWN COLLECTOR CURRENT
0
2
4
6
8
10
12
77
195
300
Temperature in ° K

N-XII-10


Second Breakdown Collector Current Increases and then Decreases as the Temperature Increases
Solitron Transistor: SES 2091-1
2N3879
R_{be} = 10 Ω
L = 40μ h
V_{be} = -5v
I_b = 2A
SECOND BREAKDOWN COLLECTOR CURRENT
0
2
4
6
8
10
12
77
195
300
Temperature in o K
64
67
84
83
7
21
31

N-XII-11



Second Breakdown Collector Current Decreases and then Increases as temperature Increases
Solitron Transistor: SES2091-1 2N3879 R_{be}=10Ω V_{be}= -5v L = 40 μ h I_b = 2 A
Second Breakdown Collector Current
0
2
4
6
8
10
12
77
195
300
Temperature in ° K
42
15
8
13
54
72
16
14
26
17
29

N-XII-12

Correlation Between Noise and Second Breakdown:-

The attached data shows the extremely meager amount of correlation between second breakdown and electrical noise. In actual figures the coefficient of correlation came to +0.465.

The thought here was that in the same family of transistors, those that had a lower current of Second Breakdown must have spiked or defective junction region and hence these junctions should show greater electrical noise. This hypothesis did not bear itself out in our measurement in the Laboratory. J.H. Durnin, W. Gee and others at NCE laboratory made the measurements over an extended period of time and Durnin has theorized this data for his Master's thesis.

At this moment our only conclusion would be that the data is encouraging but what has to be done is to find a method of noise measurement over a very short period of time but using very high forward current. If future funds became available this study should prove helpful.

DATA AND GRAPHS

ON

SECOND BREAKDOWN AND

ELECTRICAL NOISE

N-XII-14

DATA AND GRAPHS

1. Definition of Symbols Used

The following symbols are used in Figures A1 through A4 and A9:

□ (■) Single (multiple) data point for a center frequency f_c of 10 hertz.

△ (▲) Single (multiple) data point for a center frequency f_c of 1 kilohertz.

R_{BE} The value of base to emitter resistance used when the second breakdown current, I_{SB}, was obtained (see Figure 3.1).

The following symbols are used in Figures A5 through A7:

I_{CBO} Collector to base leakage current with the emitter open circuited

I_{CBX} Collector to base leakage current with the emitter at the stated condition

R_{BE} The value of base to emitter resistance used when the noise voltages, V_n, shown were recorded (see Figure 3.4b).

○ (●) Single (multiple) data point for a leakage current of 1 milliampere.

□ (■) Single (multiple) data point for a leakage current of 5 milliamperes.

△ (▲) Single (multiple) data point for a leakage current of 10 milliamperes.

X Common data point for leakage currents of 1, 5, 10 milliamperes.

The following symbols are used in Figure 8:

□ Data point for a collector current, I_c, of 0.01 amperes.

△ Data point for a collector current, I_c, of 0.03 amperes.

○ Data point for a collector current, I_c, of 0.06 amperes.

X Data point for a collector current, I_c, of 0.10 amperes.

● Data point for a collector current, I_c, of 0.35 amperes.

TABLE A1

SECOND BREAKDOWN CURRENT, I_{SB}, IN AMPERES

Unit No.	R_{BE} = 10 ohms				R_{BE} = 20 ohms			
	300° K	273° K	195° K	77° K	300° K	273° K	195° K	77° K
2	6.3	6.9	10.4	>11.0	8.4	10.0	>12.0	>11.0
7	2.3	2.3	8.0	6.0	2.9	3.1	12.0	6.4
8	8.0	8.0	2.7&8.4	8.8	9.6	9.6	11.2	12.3
10	6.3	7.2	8.2	11.8	8.8	9.6	10.0	13.4
12	3.2	3.2	4.4	7.4	3.7	3.9	8.4	9.0
13	4.1	4.2	2.8&6.6	5.0&9.2	5.4	6.4	9.6	7.0&12.3
14	5.6	3.7	2.6&8.0	9.0	8.0	>11.0	11.0	11.7
17	2.0	2.0	1.6	2.1	2.0	2.0	2.0	2.0
18	3.8	3.4	5.6	8.0	4.1	4.2	10.0	11.0
19	2.0	2.0	1.8	1.8	2.0	2.0	2.0	1.9
20	6.1	7.0	8.4	11.6	9.0	11.0	>12.0	>13.0
21	3.1	2.5	3.5	1.7&2.7	3.5	3.4	8.0	3.4
24	3.6	4.0	10.3	10.8	-	-	-	-
26	9.0	9.4	8.8	11.5	11.0	11.2	10.8	>12.0
27	1.6	1.6	1.6	1.6	1.7	1.7	1.8	1.9
28	4.0	4.7	9.4	12.5	6.0	8.0	13.0	14.0
30	6.0	7.2	9.2	10.8	8.5	9.6	10.7	>12.0
31	6.3	5.5	7.8	6.2	8.2	7.3	1.0	9.0
33	3.3	3.2	4.7	8.0	4.2	4.4	8.0	11.6
34	6.2	6.4	9.3	11.0	7.6	8.8	11.7	-
35	5.5	6.0	8.0	9.2	8.0	8.8	9.4	11.6
36	7.2	7.8	10.1	10.1	9.2	10.5	12.0	13.0
37	2.3	2.2	1.8	1.6	2.1	2.1	2.1	2.0
39	6.0	6.3	7.3	7.6	7.6	7.7	9.2	10.8

Table A1 - Second Breakdown Current, I_{SB}, In Amperes (cont'd)

Unit	R_{BE} = 10 ohms				R_{BE} = 20 ohms			
No.	300° K	273° K	195° K	77° K	300° K	273° K	195° K	77° K
41	6.2	6.7	7.9	8.4	7.9	8.7	11.0	10.8
47	3.5	3.3	9.5	10.8	10.0	10.4	12.0	>12.0
48	2.2	2.2	2.1&4.8	2.1	2.4	4.8	5.6	5.9
50	2.2	2.2	2.0	2.1	2.0	2.0	1.9	1.8
51	6.5	7.3	9.3	10.0	9.2	10.4	11.4	11.6
52	2.6	2.6	5.0	7.2	4.2	4.8	8.4	10.4
53	1.7	1.8	1.3	1.4	1.7	1.8	1.6	1.6
54	2.1	2.0	1.8	1.9	2.2	2.1	2.0	2.0
56	3.0	3.4	3.0&5.0	9.0	4.3	6.8	9.5	10.5
57	5.4	6.7	8.0	9.2	8.7	9.5	9.4	11.0
58	1.3	1.2	1.2	1.0	1.3	1.2	1.2	1.1
59	2.1	2.1	2.1	2.0	2.0	2.0	2.0	1.9
61	5.8	6.1	8.0	>8.5	7.7	8.7	11.0	>9.0
62	5.8	6.5	8.4	10.4	8.6	10.0	11.0	>13.0
64	8.2	9.8	10.8	2.6&12.0	-	-	-	-
69	2.2	2.0	1.5	1.9	2.0	1.9	2.0	1.8
70	1.9	1.8	1.5	1.4	2.0	1.8	1.8	1.8
71	6.4	7.4	10.0	<0.5	8.9	10.0	11.6	0.0
72	2.1	1.9	1.7	2.0	2.1	2.0	2.1	2.0
76	5.5	4.5	4.1	8.8	6.6	6.0	5.2	9.8
77	4.6	4.3	6.5	7.0	5.6	5.6	9.2	9.5
78	2.7	2.6	4.4	5.8	3.6	4.1	7.2	7.6
79	4.3	4.6	-	9.7	6.8	8.4	-	11.5
80	4.7	5.4	8.0	11.7	5.9	7.3	12.0	13.0
83	5.4	5.7	8.8	3.6	7.6	8.5	10.4	4.2&12.6
84	3.4	3.6	5.8	5.5	4.4	4.8	8.0	7.6
85	2.5	2.5	4.4	5.4	3.4	5.8	7.2	6.0
86	7.0	6.8	8.2	11.2	8.4	>11.0	>12.0	-
87	1.5	1.4	1.5	1.3	1.6	1.5	1.8	1.6

Table A1 - Second Breakdown Current, I_{SB}, In Amperes (cont'd)

Unit	R_{BE} = 10 ohms				R_{BE} = 20 ohms			
No.	300° K	273° K	195° K	77°K	300° K	273° K	195° K	77° K
89	1.5	1.4	1.4	1.4	1.6	1.5	1.6	1.5
94	3.3	3.0	3.0	2.8	-	-	-	-
95	4.2	5.4	7.3	>12.0	-	-	-	-
96	3.5	3.3	-	5.2	4.4	4.9	-	6.0&9.0
98	4.1	4.0	5.2	7.6	4.8	5.0	7.6	8.2
100	3.8	4.2	7.0	7.0	5.2	6.0	8.0	8.8

NOTES:
a) All readings taken on second breakdown test set.

b) Inductance was 40 μ henries.

c) Base drive was set at 2 amperes.

d) Base reverse bias, V_{BE}, was -5 volts.

e) Readings, such as >10, indicate IS_B greater than the current listed (caused by uncertainties in readings or power supply limitations).

f) Readings, such as 2.1&6.4, indicate multiple second breakdown currents.

TABLE A2

COLLECTOR TO BASE NOISE VOLTAGES,

V_n, IN MICROVOLTS RMS

(Readings Taken at Given I_{CBO})

Unit No.	I_{CBO} = 2 Microamp. f = 10 hz.	I_{CBO} = 2 Microamp. f = 1 khz.	I_{CBO} = 1 Milliamp. f = 10 hz.	I_{CBO} = 1 Milliamp. f = 1 khz.
7	3	0.9	12	3.5
8	72	63	220	240
10	180	180	12	3
12	45	35	18	7
13	55	50	240	200
14	18	10	30	10
17	250	230	10	3
18	2200	1	50	5.5
19	10	2.1	90	10
20	9	5.8	25	9
21	540	8	25	2.6
24	120	110	150	90
26	2.6	0.38	-	-
27	190	260	160	130
28	110	150	60	40
30	3.0	0.4	600	30
31	60	0.6	1200	550
33	280	440	220	200
34	620	750	720	520
35	130	0.5	500	32
36	30	34	58	35
37	170	180	20	12
39	3.5	0.38	-	-
41	48	40	170	160
47	3.0	0.38	-	-
48	5	0.4	10	5
50	70	100	100	75
51	450	480	1400	200
52	5.4	2.1	30	23
53	8	2	42	9
54	32	8.8	160	180
56	1000	7	150	80
57	200	3.2	30	5
59	6	8	58	10

Table A2 (cont'd)

Collector to Base Noise Voltages,
V_n, in Microvolts RMS
(Readings Taken at Given I_{CBO})

Unit No.	I_{CBO} = 2 Microamp. f = 10 hz.	I_{CBO} = 2 Microamp. f = 1 khz.	I_{CBO} = 1 Milliamp. f = 10 hz.	I_{CBO} = 1 Milliamp. f = 1 khz.
61[d]	30	5	20	24
62	110	170	20	10
64	170	190	27	27
67	-	-	-	-
69	8	1.6	21	4.5
70	2.5	0.75	18	4
71	220	200	5	1.5
72	150	130	20	15
76	290	260	150	120
77	100	90	15	6
78	6	4.5	10	7
79	250	210	420	400
80	200	110	12	3.5
83	100	80	50	30
84	300	270	16	3.5
85	180	170	30	30
86	14	1.2	500	300
87	16	2.2	130	12
89	3.0	0.5	30	10
94	160	140	60	50
95	100	60	60	40
96	220	170	300	15
98	600	600	21	5
100	200	150	15	5

NOTES:

a) Symbol I_{CBO} means Collector to Base Reverse Current, With Emitter Open Circuited.

b) A one hertz band width was used at the frequencies listed.

c) All measurements were taken on a Quan. Tech. Labs Model 327 Diode Noise Analyzer.

d) Unit numbers 61 through 77 have readings listed for I_{CBO} = 2 milliamp. - not I_{CBO} = 1 milliamp.

TABLE A3

COLLECTOR TO BASE NOISE VOLTAGE
SPECTRUM

(Noise Voltages in Microvolts;
Band Width = 100 hz.)

Unit No.	Center Frequencies				
	100 hz.	1 khz.	5 khz.	10 khz.	100 khz.
	I_{CBO} = 1 Milliampere				
12	440	220	16	8	2
13	460	240	16	9	1
14	430	220	18	10	2
17	420	240	18	11	2
	I_{CBO} = 5 Milliamperes				
12	740	260	12	8	2
13	750	270	10	11	2
14	710	260	10	6	2
17	680	280	11	6	2
	I_{CBO} = 10 Milliamperes				
12	780	360	13	14	2
13	760	390	26	14	2
14	720	370	25	19	2
17	740	360	24	12	2

NOTES: a) Quan. Tech. Labs Model 303 Wave Analyzer used for all measurements.

b) Collector current limiting resistor was 10,000 ohms.

c) Test Circuit Figure 3.4a; Noise Voltage Spectrum plotted in Figure A5.

TABLE A4

COLLECTOR TO BASE NOISE VOLTAGE
SPECTRUM WITH EMITTER REVERSE BIASED
(Noise Voltages in Microvolts;
Band Width = 100 hz.)

Unit No.	Center Frequencies				
	100 hz.	1 khz.	5 khz.	10 khz.	100 khz.
	I_{CBX} = 1 Milliampere; R_{BE} = 10 Ohms				
12	16	11	6	5	2
13	12	8	5	4	2
14	14	10	5	4	2
17	11	8	6	5	3
	I_{CBX} = 5 Milliamperes; R_{BE} = 10 Ohms				
12	58	58	60	58	43
13	92	46	43	58	26
14	48	42	40	42	32
17	10	7	4	3	2
	I_{CBX} = 10 Milliamperes; R_{BE} = 10 Ohms				
12	12	10	9	8	8
13	20	18	18	16	15
14	16	15	14	14	14
17	18	16	17	16	13
	I_{CBX} = 1 Milliampere; R_{BE} = 20 Ohms				
12	14	10	6	4	2
13	52	20	4	2	2
14	18	13	6	5	2
17	14	11	8	8	9

Table A4 (cont'd)

Collector to Base Noise Voltage
Spectrum With Emitter Reverse Biased

(Noise Voltages in Microvolts;
Band Width = 100 hz.)

Unit No.	Center Frequencies				
	100 hz.	1 khz.	5 khz.	10 khz.	100 khz.
	I_{CBX} = 5 Milliamperes; R_{BE} = 20 Ohms				
12	68	58	58	56	42
13	60	60	56	52	12
14	30	28	26	26	25
17	10	8	5	6	4
	I_{CBX} = 10 Milliamperes; R_{BE} = 20 Ohms				
12	12	10	8	7	6
13	23	23	22	22	18
14	16	12	10	9	9
17	18	18	19	20	14

NOTES: a) Quan. Tech. Labs Model 303, Wave Analyzer used for all measurements.

b) Collector current limiting resistor was 10,000 ohms.

c) Test Circuit Figure 3.4b ; Noise Voltage Spectrum plotted in Figures A6 and A7.

d) Symbol I_{CBX} means Collector to Base Reverse Current under stated conditions (base to emitter at 5 volts reverse bias).

TABLE A5

COLLECTOR TO BASE NOISE VOLTAGE SPECTRUM WITH I_C FLOWING

(Noise Voltages in Microvolts; Band Width = 100 hz.)

Unit No.	Noise Voltage for Given I_C (In Amperes)				
	0.01	0.03	0.06	0.10	0.35
56	33	65	85	93	31
19	37	67	88	95	31
10	35	68	88	92	33
27	28	55	78	86	31
30	28	55	75	90	32
31	30	56	81	89	32
33	30	53	76	84	31
34	30	58	78	88	32
35	29	54	78	88	30
36	30	49	80	85	29
37	30	58	80	87	28
40	30	58	81	90	29
50	31	59	82	92	29
51	31	59	82	90	30
54	31	59	82	90	30
59	31	58	79	88	30
62	31	58	81	88	29
76	30	57	80	88	29

NOTES:

a) Quan. Tech. Labs Model 303 Wave Analyzer used for all measurements.

b) Collector current limiting resistor was 100 ohms.

c) Test Circuit Figure 3.5; Noise Voltage Spectrum plotted in Figure A8.

d) Symbol I_c means current flowing into the collector terminal.

e) Center frequency, f_c = 100 hz.

TABLE A6

BASE TO EMITTER NOISE VOLTAGES, V_n, IN MICROVOLTS RMS

Unit No.	Noise Voltage for Given I_{EBO}					
	5 Microamp.		1 Milliamp.		3 Milliamp	
	10 hz.	1 khz.	10 hz.	1 khz.	10 hz.	1 khz.
7	4.0	0.45	7.5	3.0	3.0	2.0
8	5.0	1.4	15.0	6.0	3.0	3.0
10	3.0	0.52	4.5	1.3	4.5	1.8
12	3.0	1.1	4.5	1.5	1.8	1.1
13	3.0	0.5	4.5	2.0	3.0	1.0
14	3.2	0.4	21.0	17.0	2.1	1.0
17	5.0	3.6	5.0	3.0	3.0	2.3
18	3.3	1.5	6.0	2.5	6.0	5.0
19	4.4	0.4	3.0	3.0	3.0	1.5
20	4.5	1.8	20.0	10.0	3.0	1.7
21	4.5	2.2	2.4	0.6	3.0	3.2
24	3.5	0.4	3.0	1.5	4.0	3.0
26	3.2	0.38	0.9	0.15	1.2	0.2
27	3.5	0.58	6.0	0.4	6.0	4.2
28	4.5	1.5	6.0	7.0	3.0	2.0
30	3.2	0.38	0.9	0.1	1.5	0.2
31	4.5	0.4	4.0	0.35	3.0	0.3
33	1.0	0.6	3.9	5.0	1.5	1.0
34	4.2	0.45	5.0	2.0	2.0	0.7
35	1.0	1.7	4.5	1.0	15.0	5.0
36	3.5	0.9	3.0	2.0	3.0	2.5
37	4.4	0.46	6.0	4.0	6.0	4.4
39	3.0	0.38	3.0	0.3	9.0	1.2
41	19.0	11.0	18.0	8.0	12.0	4.0
47	3.5	0.38	1.0	0.1	2.0	0.1
48	3.5	3.2	3.0	1.0	2.4	1.3
50	3.8	0.4	5.4	0.7	3.8	2.1
51	4.0	2.5	1.5	1.5	2.4	1.5
52	4.0	0.5	1.0	0.4	4.0	2.5
53	3.5	0.4	4.0	1.4	10.0	1.2
54	2.8	0.4	2.5	0.6	3.5	1.8
56	3.6	1.2	2.2	1.0	2.1	1.0

Table A6 (cont'd)

Base to Emitter Noise Voltages,
V_n, In Microvolts RMS

Unit No.	Noise Voltage for Given I_{EBO}					
	5 Microamp.		1 Milliamp.		3 Milliamp.	
	10 hz.	1 khz.	10 hz.	1 khz.	10 hz.	1 khz.
57	3.8	0.4	5.0	3.0	2.7	2.5
59	22.0	11.0	6.2	3.1	2.9	2.9
61	3.5	0.5	5.2	4.3	3.8	2.8
62	3.4	0.38	4.4	1.1	4.4	3.0
64	5.5	3.0	5.0	4.2	5.2	3.8
69	4.0	0.4	10.0	7.5	6.5	5.0
70	3.0	0.9	8.0	6.6	2.4	2.0
71	3.0	0.4	1.8	1.3	3.5	2.0
72	3.0	0.4	3.3	1.5	3.3	1.9
76	2.5	0.4	1.5	1.2	2.1	1.9
77	2.5	0.38	4.5	1.0	2.1	1.1
78	4.2	1.7	3.6	2.1	1.5	1.0
79	2.8	0.5	1.0	0.7	2.7	0.7
80	4.0	0.4	2.4	0.6	3.9	0.8
83	4.0	0.44	5.2	3.2	4.2	1.7
84	4.0	0.4	0.9	0.4	3.3	1.4
85	3.6	0.4	5.5	5.2	2.6	1.8
86	5.0	0.65	4.2	2.2	4.4	3.2
87	4.5	0.8	3.0	1.4	3.8	2.5
89	4.5	0.4	4.4	3.2	4.0	2.6
94	6.0	4.0	5.0	1.4	3.5	0.8
95	12.0	8.0	2.4	0.7	2.8	2.8
96	3.5	0.4	1.8	0.7	2.7	0.8
98	3.5	0.4	1.8	0.4	2.7	0.6
100	5.0	0.55	3.6	0.3	3.9	2.3

NOTES: a) Quan. Tech. Labs Model 327 Diode Noise Analyzer used on all measurements.

b) A one hertz band width was used at the frequencies listed.

c) Symbol I_{EBO} means base to emitter reverse current, with collector open circuited.

d) Test Circuit Figure 3.3b , except that for 5 microamp. measurement the 10 meg-ohm resistor was replaced by a 50 meg-ohm resistor.

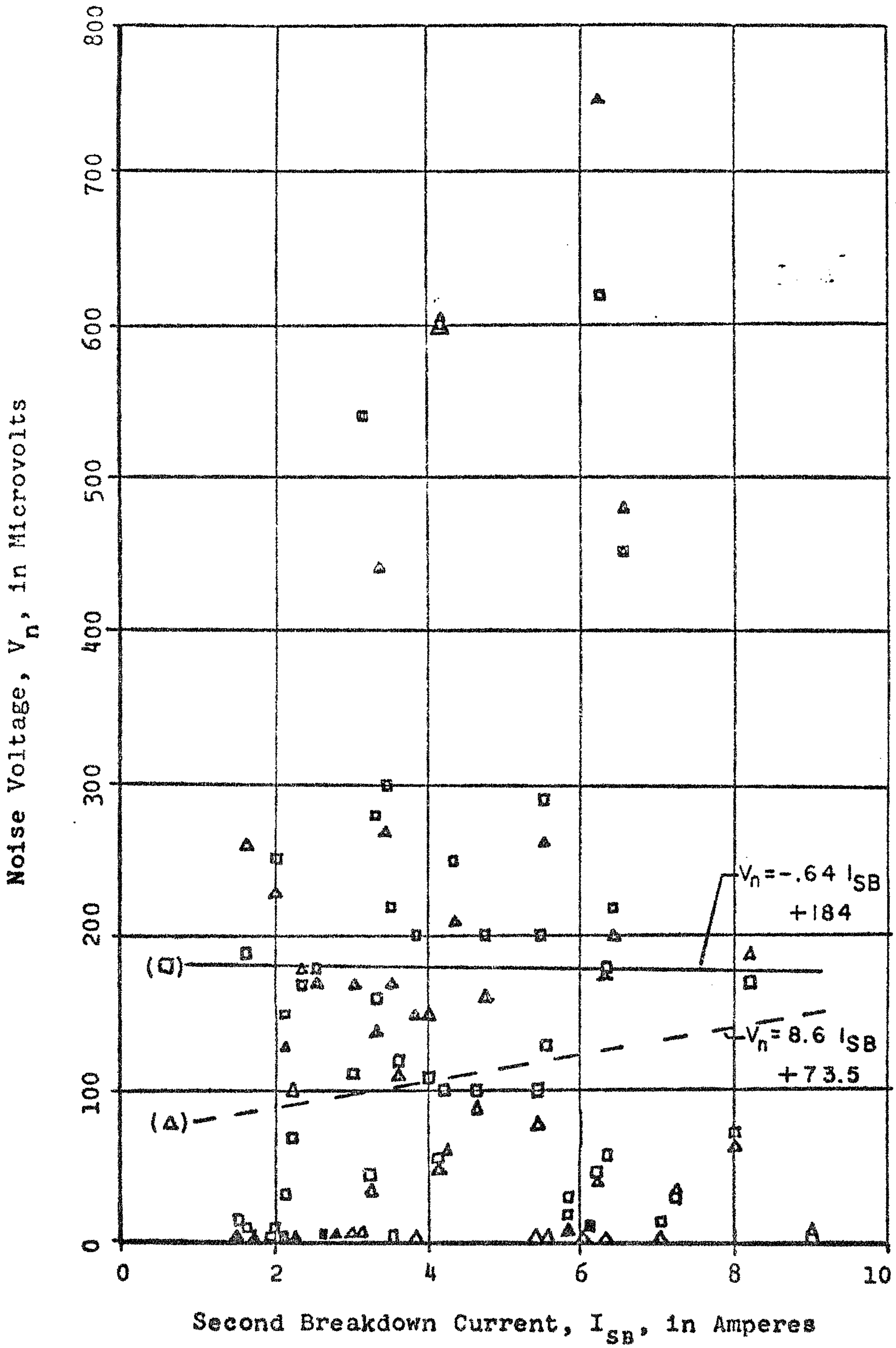


Figure A1 -- Noise Voltage vs. Second Breakdown Current

(I_{CBO} = 2 amp.; R_{BE} = 10 ohms)

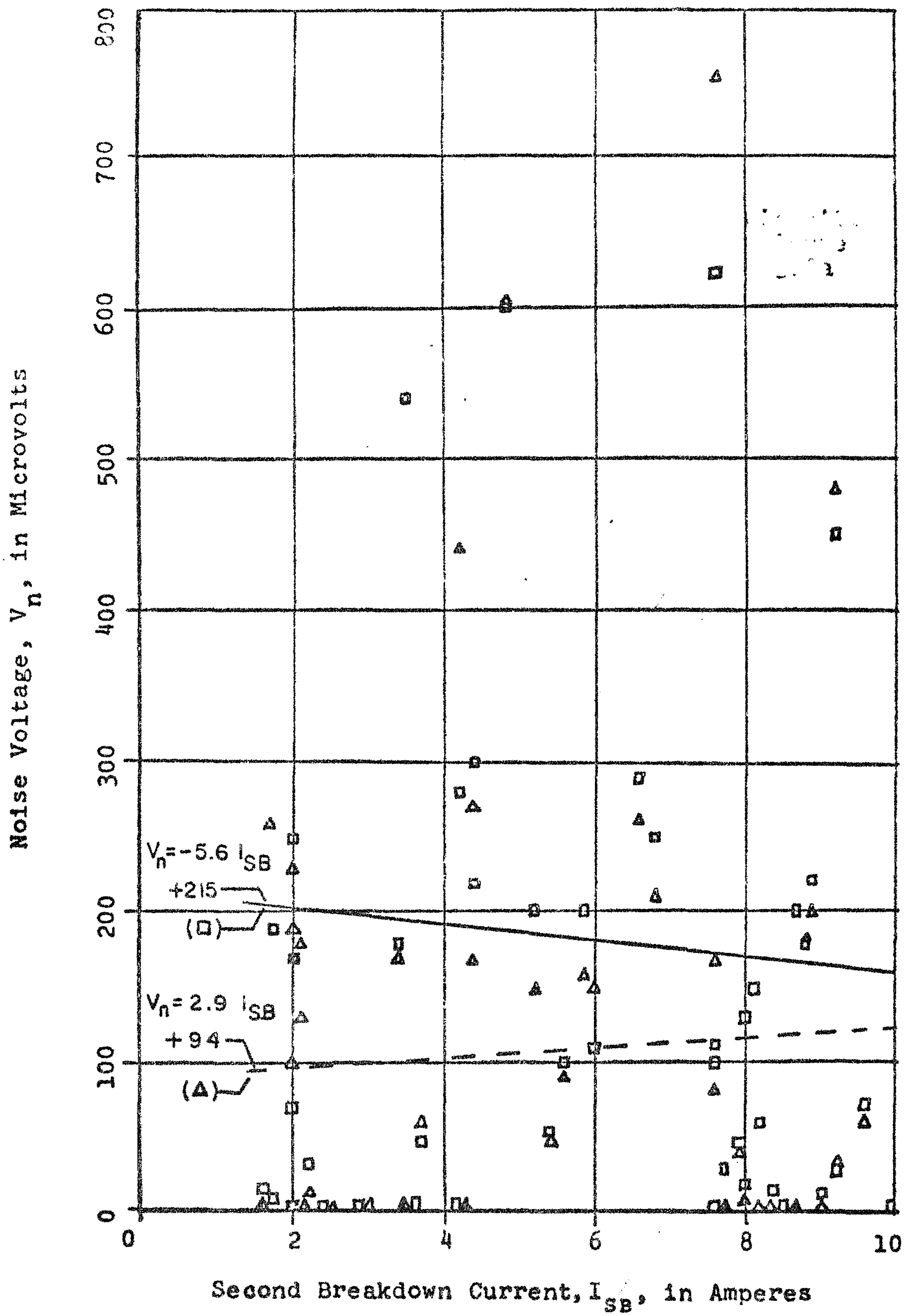


Figure A2 -- Noise Voltage vs. Second Breakdown Current

(I_{CBO} = 2 amp.; R_{BE} = 20 ohms)

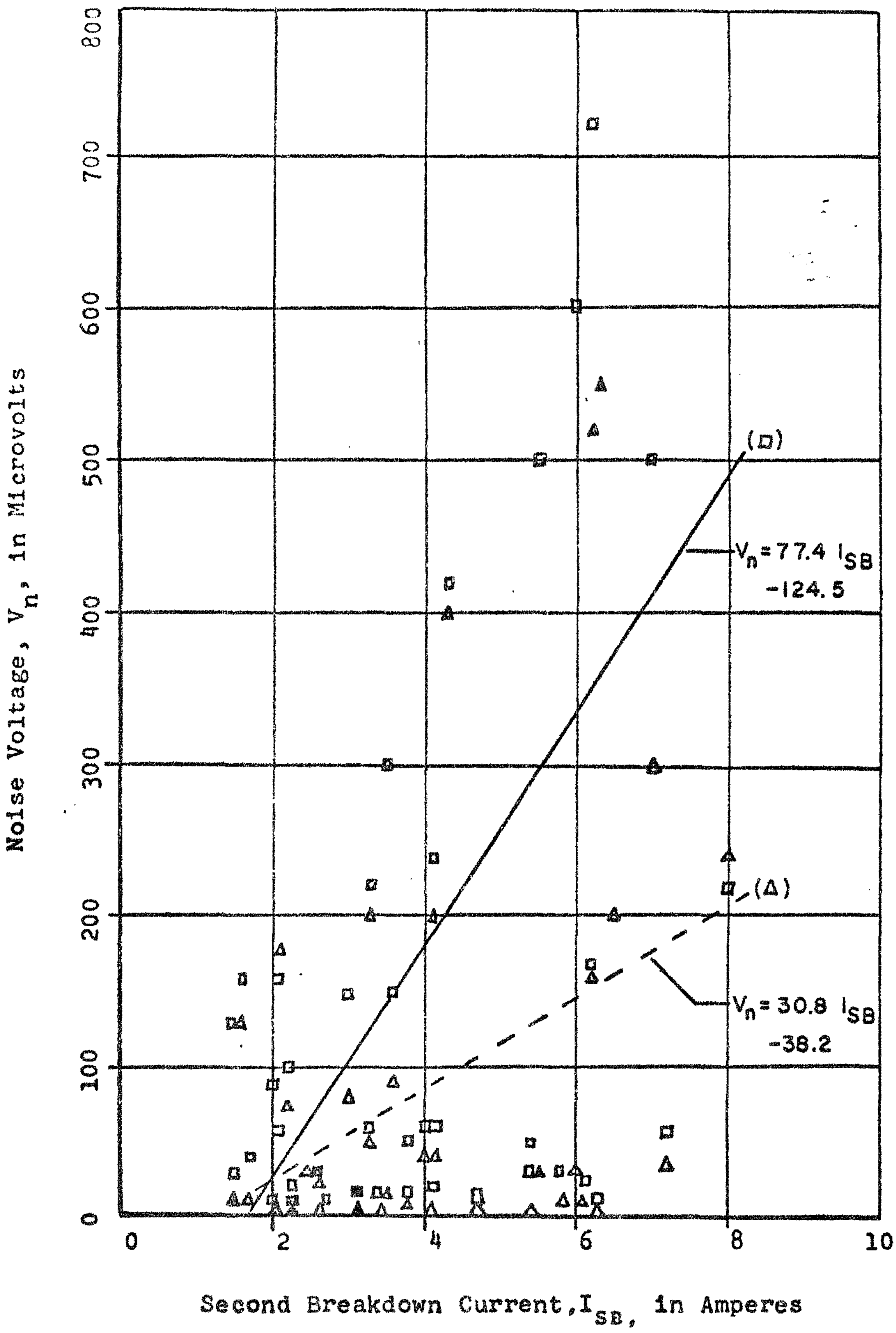


Figure A3 -- Noise Voltage vs. Second Breakdown Current

(I_{CBO} = 1 amp.; R_{BE} = 10 ohms)

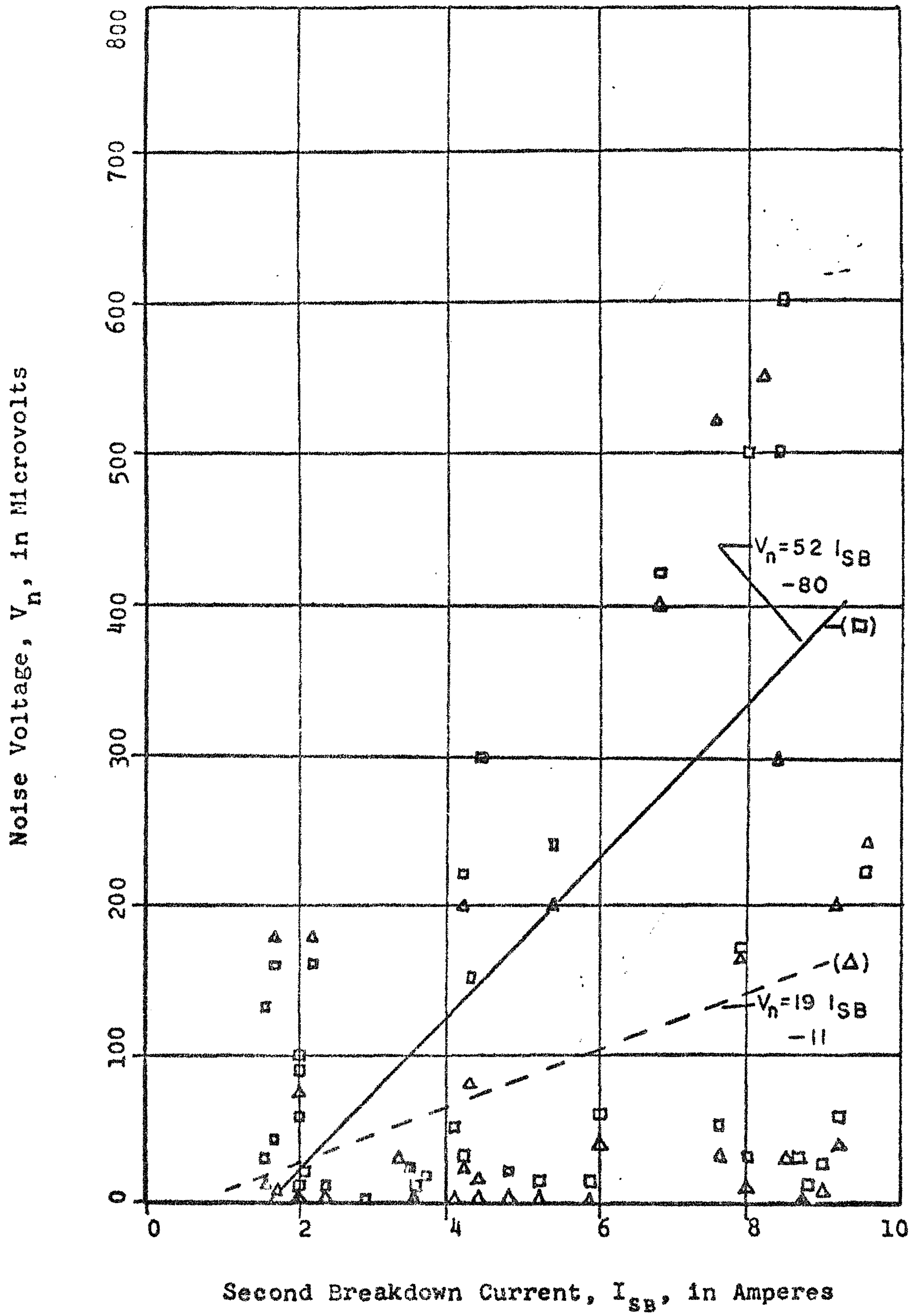


Figure A4 -- Noise Voltage vs. Second Breakdown Current

(I_{CBO} = 1 amp.; R_{BE} = 20 ohms)

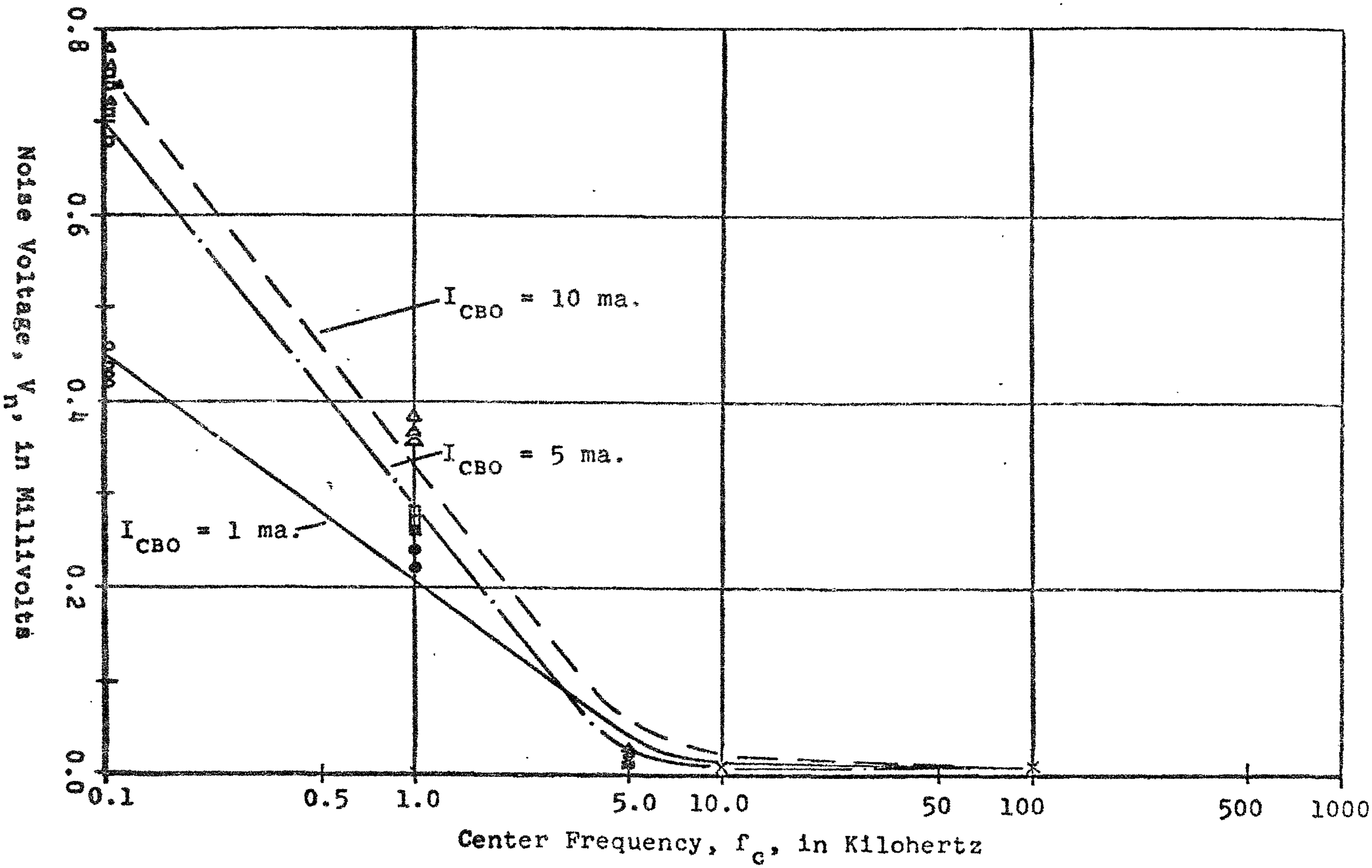


Figure A5 -- Noise Voltage Spectrum (I_{CBO} Condition)

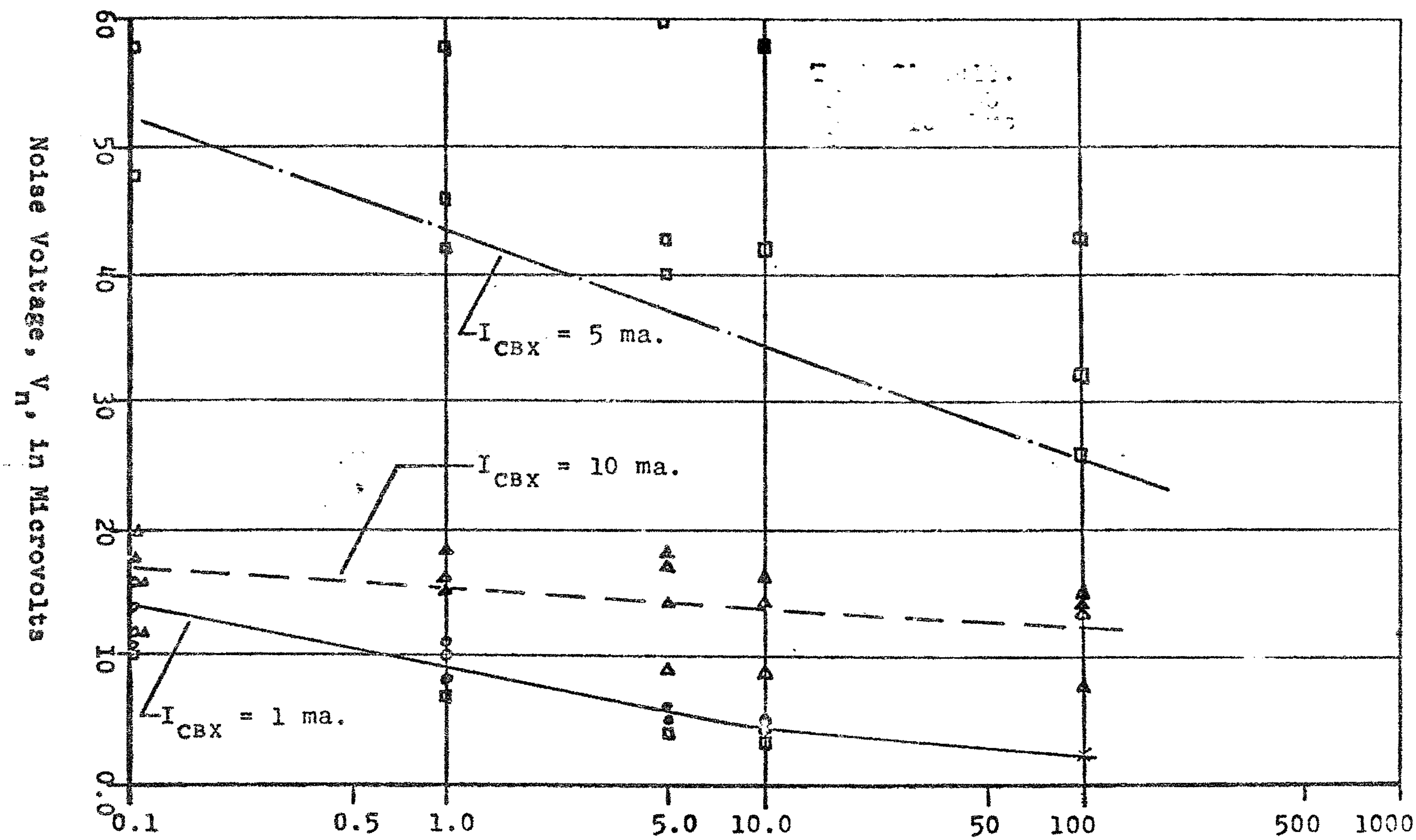


Figure A6 -- Noise Voltage Spectrum (I_{CBX} Condition)

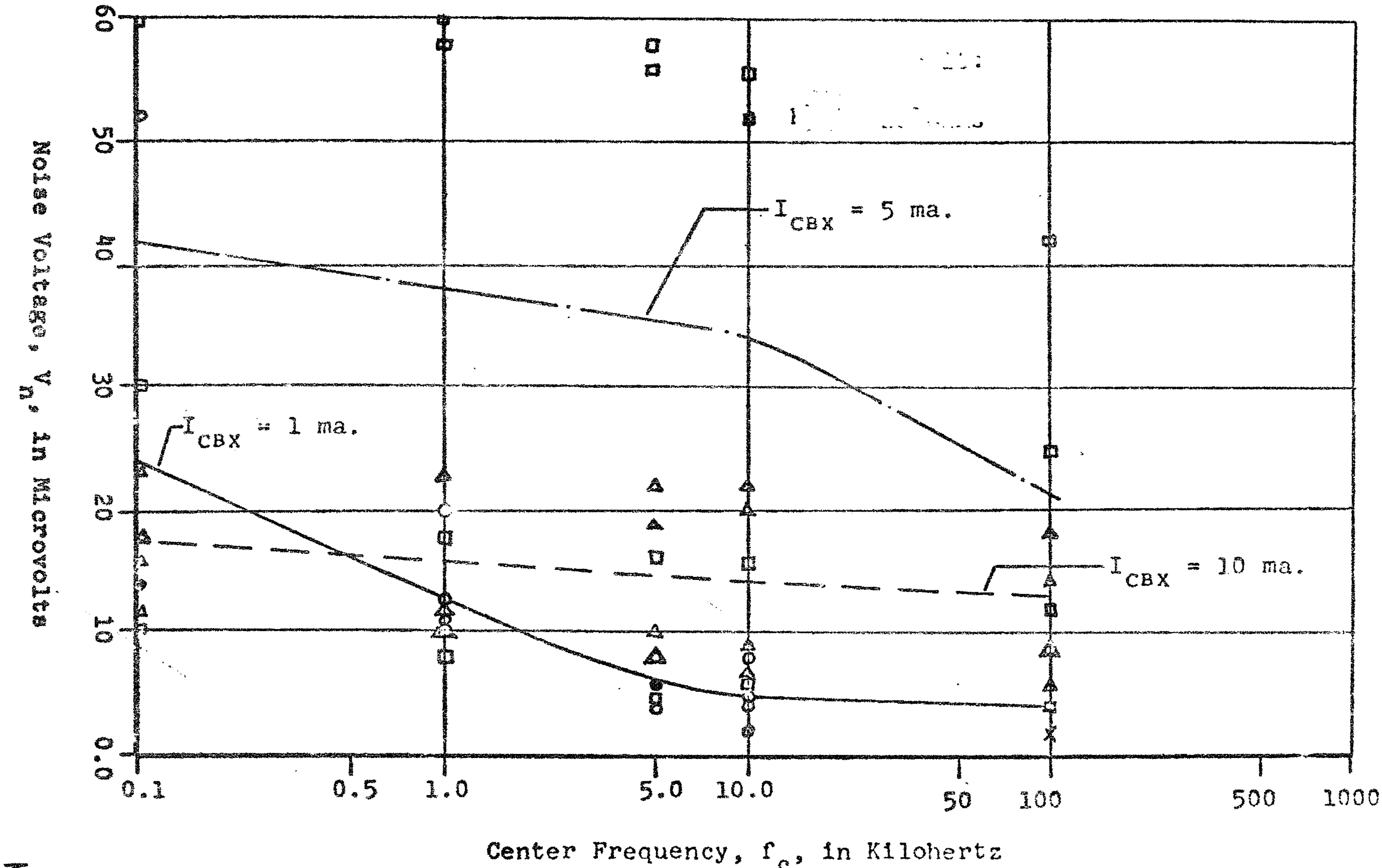


Figure A7 -- Noise Voltage Spectrum (I_{CBX} Condition)

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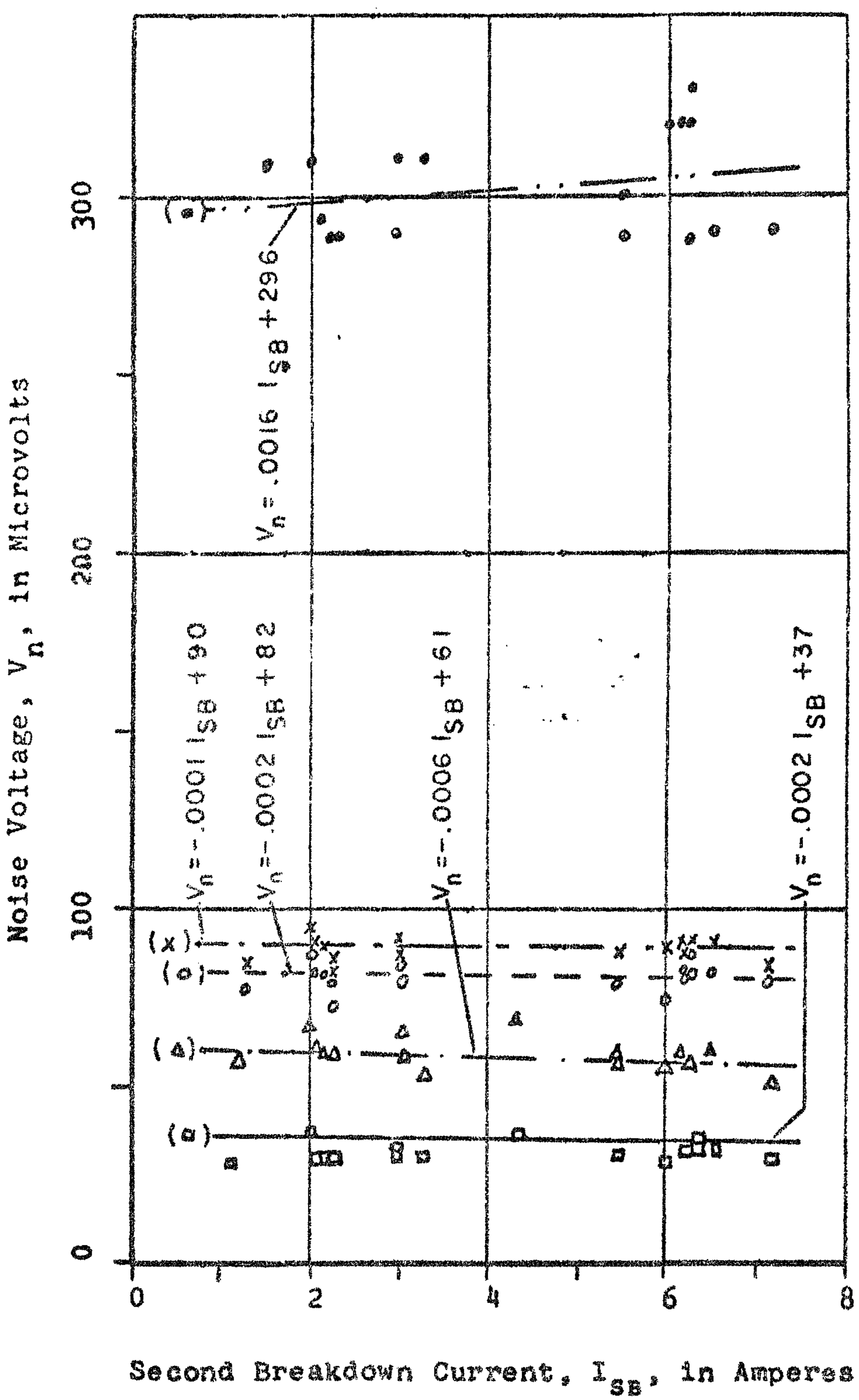

Figure A8 -- Noise Voltage vs. Second Breakdown Current

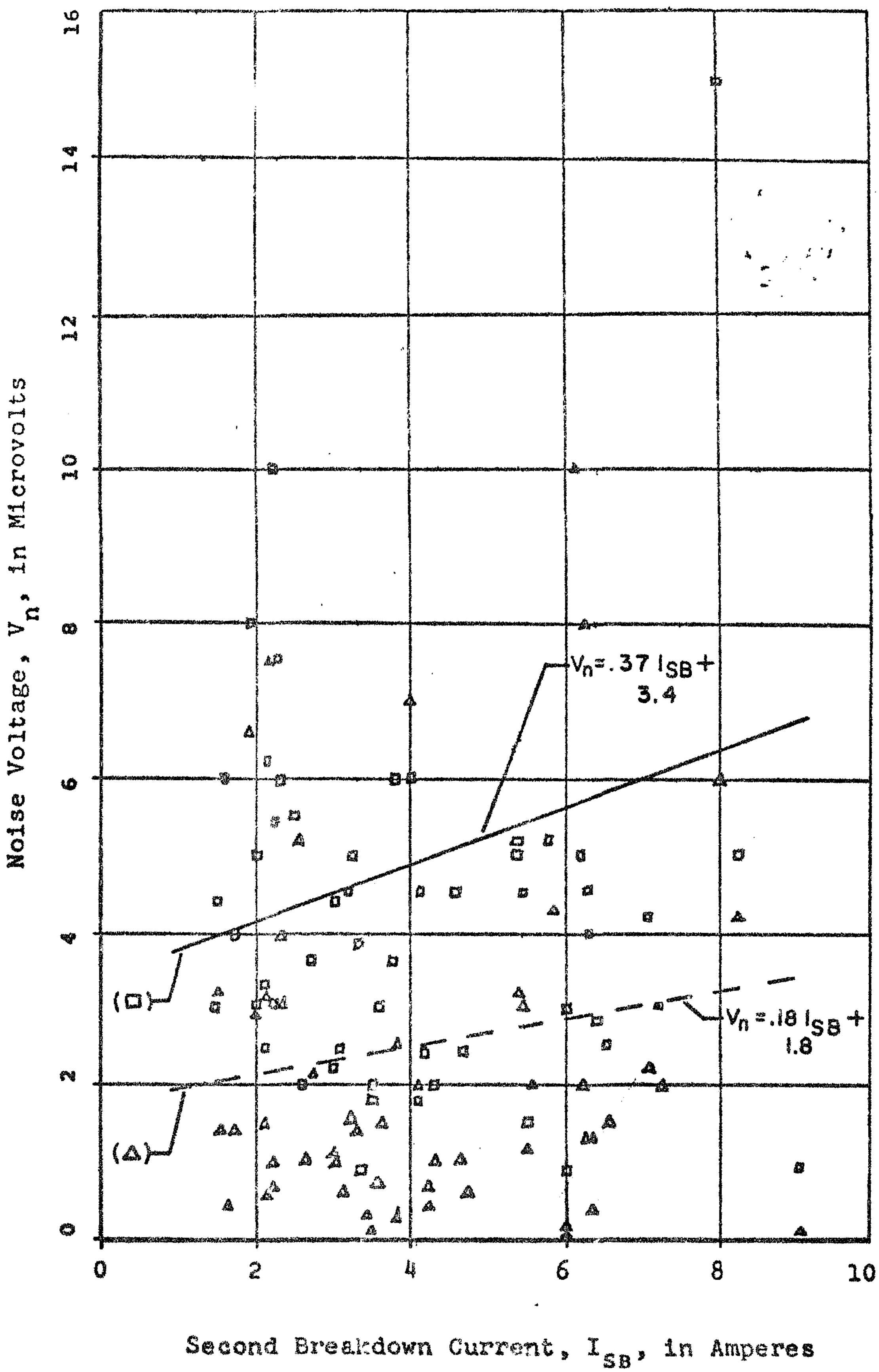

Figure A9 -- Noise Voltage vs. Second Breakdown Current
(I_{EBO} = 1 amp.; R_{BE} = 10 ohms)

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